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Design and Analysis of Three Wheeled Dual Steering Vehicle

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***Abstract--*. The main aim of this study is to carry out design and analysis of a three wheeled vehicle that has steering on both sides which is powered by hub motors. The design is carried out by using PTC CREO 2.0 software and analysis is executed using ANSYS 14.5 software. Considering the results, this vehicle is fabricated by using 1090mild steel for chassis, swing-arm and Wishbones (A-arms). In this study, it is determined that the turning radius of the wheel is obtained by using all wheel steering mechanism and it is relatively smaller than actual turning radius. The equivalent stress values are also determined for safe design.**

Keywords – Chassis, Wishbone, Swing-arm, Steering geometry, FEA

I INTRODUCTION

A three-wheeler is a vehicle than runs on three wheels which iseither human powered vehicle (HPV) or motorized vehicles in the form of a motorcycle, all-terrain vehicle (ATV) or automobile. Many three-wheelers which exist in the form of motorcycle-based machines are often called trikes and often have the front single wheel and mechanics similar to that of a motorcycle and the rear axle similar to that of a car.Three-wheeled automobiles can have either one wheel at the back and two at the front or vice versa. The three wheeled vehicle that have two wheels in front and one wheel on the rear side are often called as reversed trikes.

Automobile companies are engaged in the design of more efficient vehicles improving the efficiency, flexibility and refining them for the best use of the current roads. The idea of flexible, efficient vehicles for personal transportation seems to naturally introduce the three wheel platform [1, 2]. During heavy traffic situations and parking conditions, it is difficult to reverse the vehicle while sitting on the front side. To avoid these problems, an idea of constructing a simple three wheeled vehicle that can carry two people which has steering system on both sides, has been implemented. This study is basically divided into three parts i.e., design of chassis and suspension components of the vehicle, calculation of turning radius and finite elemental analysis.

The design part deals with the design of chassis and suspension systems of the vehicle using PTC CREO 2.0.The type of suspension system used is double wishbone type on two wheel side while swing-arm is used on the single wheel side.

The turning radii of the vehicle while steering on single wheel side and while steering on two wheel side are calculated by using all wheel steering mechanism. This paper aimed to predict the structural analysis of chassis and suspension system is carried out in order to verify the maximum equivalent stress on the vehicle which confirms the factor of safety.

II DESIGN

The designis majorly classified into two parts i.e., design of chassis and design of suspension system.

A.Design of Chassis

Table 1. The material properties of mild steel

Material Properties	
Type of Material Used	1090 Mild Steel (low carbon steel)
Young's Modulus	210×10^9 Pa
Yield Strength	248×10^6 Pa
Poisson's Ratio	0.305
Density	7580 kg/m^3
Ultimate Strength	841×10^6Pa
Cross Section	4×4 cm
Thickness	0.3 cm

The chassis must be able to withstand the force from cabin and force due to battery andit should be able to support the suspension system of the vehicle. To achieve this, space frame type of chassis has been used. This chassis provides design flexibility to alter and meet the necessary design criterion.The material properties are given in the table 1.

As two passengers must be accommodated, a width of 117 cm, length of 170cm and height of 25cmwere considered in this design, so that two steering mechanisms are placed and as this vehicle is powered by two Brushless DC hub motors which are attached to the two wheels on the front side and therefore differential drive is not required for this vehicle. Considering all the above factors, the chassis is designed and the top view is shown in the figure 1

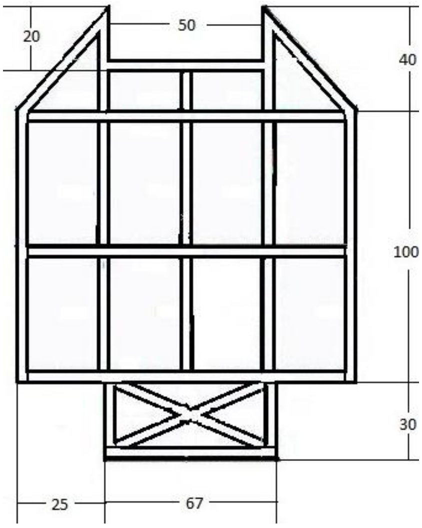

Figure 1. Top view of the wireframe model of the chassis (all units are in cm)

The chassis is divided into two areas and is represented below in figure 2

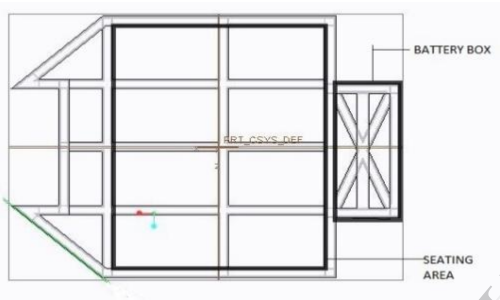

Figure 2. Wireframe model of chassis showing the location of seating area and battery box

Since, the diameter of the single wheel is 35cm, a maximum clearance of 50 cm is given on the single wheel side of the chassis. This is shown in figure 3.

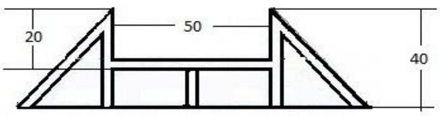

Figure 3. The top view of the wireframe model on single wheel side of chassis (all units are in cm)

The seating area is considered in such a way that two passengers are accommodated comfortably and must withstand the weight of two persons and it is shown in figure 4.

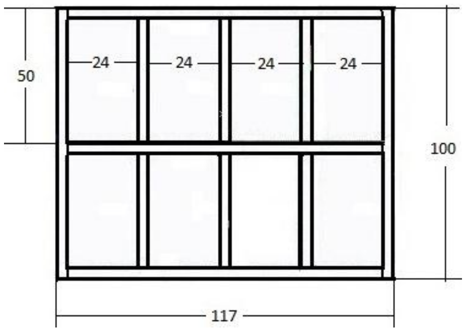

Figure 4. The top view of the wireframe model on seating area of the chassis (all units are in cm)

The two wheel side of the vehicle, also known as battery box, is considered in such a way that sufficient space is left for placement of suspension systems and this area is mainly designed for placing battery, which is shown in figure 5.

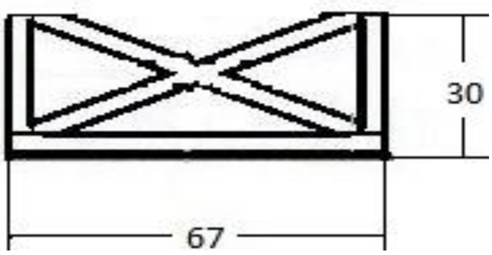

Figure 5. The top view of the wireframe model on the battery area of the chassis (all units are in cm)

The total height of the chassis was taken as 25 cm which is provided with the crossbars and is shown in figure 6. The cross bars on the sides were taken in order to provide support to the vehicle body or any other loads falling on the body of the vehicle and is shown in figure 7. The crossbars on the single wheel side of the chassis were taken, so that rigidity was provided and unnecessary deformations were avoided in the chassis and are shown in figure 8. The 3D model of the entire chassis is shown in figure 9.

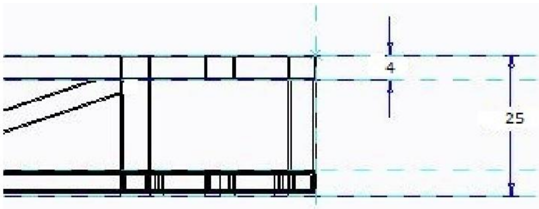

Figure 6 : Height of the chassis shown from the wireframe model of the chassis (all units are in cm)

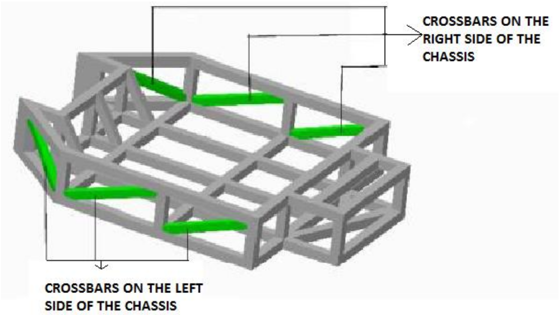

Figure 7 : Crossbars on the sides of the chassis

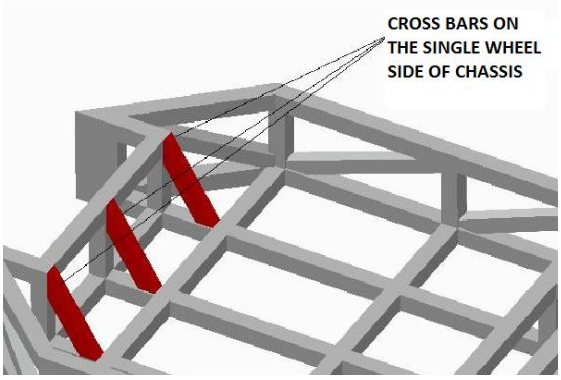

Figure 8 : Crossbars on the single wheel side of the chassis

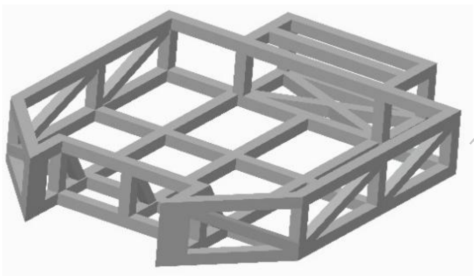

Figure 9: 3D model of the chassis modelled using PTC CREO 2.0

B. Design of wishbone

Suspension system provides damping effect to the vehicle. Here, two types of suspension systems are used in this vehicle. The double wishbone type suspension was used for the wheel side of the vehicle while the swing arm was used on the other side.

The wishbones are standard A-arms and the length and width constraints verify the dimensions. The upper wishbone is relatively shorter than the lower wishbone respect to linear dimensions. The main advantage of considering different lengths is that when the vehicle takes a turn, negative camber is induced which increases the stability. The unequal lengths also result in a positive camber of 1.5^0.The shock absorber is mounted on the lower wishbone and the knuckle is attached to the wishbone by a ball joint[3, 4].

Since the length of the tie rod is 163 cm and the vertical distance between seating area and battery box is 25 cm, the linear length of the wishbone is taken as 30 cm. The width of the A-arm is taken as 30 cm because it must align with the battery box.

By considering the above factors, the wishbone is designed and is represented as shown below in figure 10 and 11.

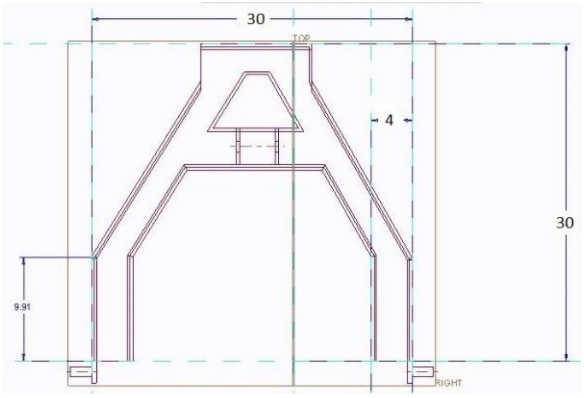

Figure 10: Dimensions of the A-arm (all units are in cm)

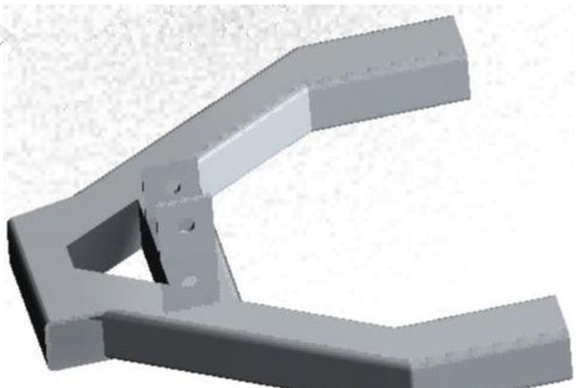

Figure 11: 3D model of A-arm

C. Design of swing-arm

The swing-arm or swing-fork is the main component of the suspension system used for two wheeler vehicles. Since there is a single wheel on one side, swing arm is used for the suspension system. Single-sided type of swing-arm is used for this vehicle in order to ensure the proper alignment of the wheel.

The length and breadth of the swing arm is considered in such a way that it does not affect the turning angle of the wheel [5]. The dimensions are shown in figure 12.The 3D model of swing arm is also shown in figure 13.

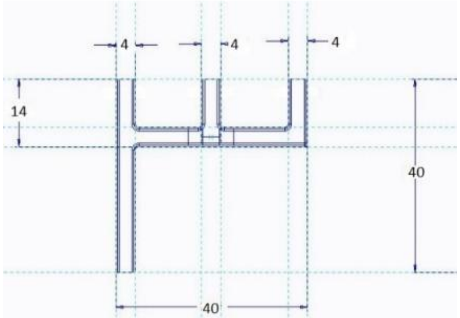

Figure 12: Dimensions of one-sided swing arm (all units are in cm)

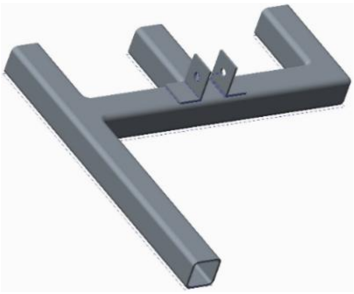

Figure 13: 3D model of swing-arm

III. CALCULATION OF TURNING RADIUS

This vehicle consists of dual steering mechanism i.e., the vehicle can be steered from both the sides and this type of mechanism is called all wheel steering. The steering systems on two sides are connected by a rotating shaft by the means of bevel gears. These are connected in such a way that when one side of the vehicle is steered, the wheels on both the sides of the vehicle make a certain turning angle. The calculation of steering geometry from figure 14 and figure 15 is as follows [6, 7].

A. Steering Geometry when two wheel side of the vehicle is steered.

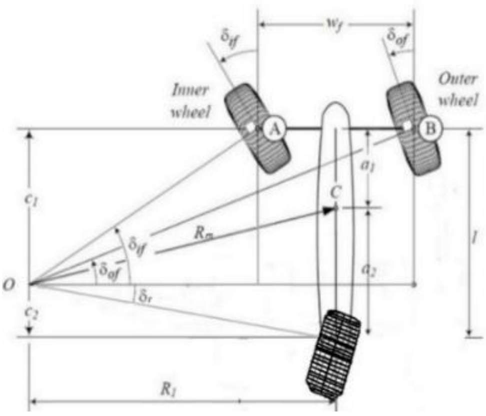

Figure 14. Steering geometry on two wheel side

The turning radius of the vehicle on the two wheel side is calculated when the outer wheel takes a left turn.

From the test it is found that the inner angle δ_{if} of two wheel side is 25.6^0 and turning radius R is 447.5 cm.

The turning radius of the vehicle is given as $R=\sqrt{{a_2}^2 + R_1^2}$

Where, R_1 (434 cm) is the distance between instantaneous centre and the axle of the vehicle and a_2 (107 cm) is the centre of gravity along vertical axis.

$$Tan(\delta_{if}) = C_1/(R_1 - w_f/2) \quad (1)$$

$$C_1 + C_2 = L \quad (2)$$

Where, C_1 = Distance of instantaneous centre from two wheel side, C_2 = Distance of instantaneous centre from single wheel side, Track width w_f = 167 cm, Length of the vehicle L = 181 cm. From the equations (1) and (2)

C_1= 152.2 cm and C_2= 28.78 cm

The outer angle of the two wheel side tyre is given in equation (3)

$$\delta_{of} = \mathrm{ArcTan}\left(\frac{C_1}{R_1 + \frac{w_f}{2}}\right) = 19.03^0 \quad (3)$$

The turning angle of the single wheel side is given in equation (4).

$$\delta_r = \left(\frac{C_1}{R_1}\right) = 5.75^0 \quad (4)$$

Thus, the total inner angle of the vehicle is

$$\delta_i = \delta_{if} + \delta_r = 31.075^0 \quad (5)$$

Total outer angle of the vehicle is

$$\delta_o = \delta_{of} + \delta_r = 24.505^0 \quad (6)$$

From equations (5) and (6),

$$\cot\delta = \frac{\cot\delta_i + \cot\delta_o}{2} = 1.92$$

The modified turning radius $(R_m)$is given in equation (7)

$$R_m = \sqrt{a_2^2 + L^2 cot^2\delta} = 363.6 \text{ cm} \quad (7)$$

Thus by using the all-wheel steering mechanism, the turning radius of the vehicle is considerably reduced when compared to the turning radius of regular automobiles (440 cm)

B. Steering Geometry when one wheel side of the vehicle is steered:

The turning radius R_S of the vehicle when conventional steering used is254.48 cm

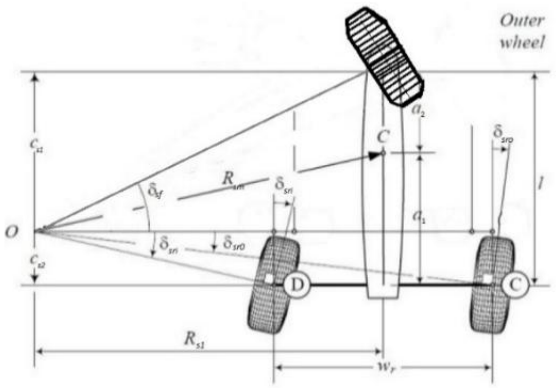

Figure 15. Steering geometry on one wheel side

Therefore, Distance between instantaneous centre and the axle of the vehicle on the single wheel side R_{s1} = 243.48 cm. Centre of gravity from the single wheel side (a_1)= 74 cm

Steering geometry of one wheel side was calculated similar to the steering geometry of two wheel side.

C_{s1} = 116.629 cm, C_{s2} = 64.373 cm, δ_{sf} = 25.6^0, δ_{sri} = 21.91^0, δ_{sro} = 11^0, R_{sm} = 216.65 cm

where C_{s1} and C_{s2} are distances of instantaneous centre from single wheel side and two wheel side respectively while δ_{sri} and δ_{sro} are inner and outer turning angles on two wheel side and R_{sm} is the modified radius while single wheel side is steered.

IV. FINITE ELEMENTAL ANALYSIS

FEA relates to a computer model that has a material or design that is stressed and analysed for specific results. It is used for refinement of new or existing product design. If there is a structural failure, FEA will help determine the modifications of design to meet the respective requirements. FEA uses a complex system of plotting of points called nodes which makes grid called a mesh. This mesh is programmed to contain the material and structural properties which defines the structure's reaction to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. Regions which receive large amounts of stress usually have a higher node density than those which experience little or no stress. The mesh acts like a spider web from each node and in that there extends a mesh element to each of the adjacent nodes. The web of vectors carry the material properties of the object, creating many elements [8, 9].

In this project, FEA is carried out on chassis, wishbone and swing-arm using ANSYS 14.5. The CAD model can be imported as either IGES or STEP format to ANSYS from PTC CREO. In this case, STEP format is chosen since there will be a minimal amount of data loss.

A. *Loads acting on the chassis*

The analysis is carried out by taking various loads and the same is shown in table 2

Table 2. Loads acting on the chassis

Two Passengers	200 kg
Battery	41.2 kg
Weight of each wheel with Hub Motor	10 kg

B. *Structural Analysis of Chassis*

The structural analysis was carried out to find out equivalent stress, strain and total deformation of the chassis. The meshed model and the properties are shown in figure 16 and table 3 respectively. Analytical results of the chassis are shown in figure 17, figure 18 and figure 19.

Figure 16. Meshed model of chassis

Table 3: Mesh Properties of chassis

No. of Nodes	554736
No. of Elements	275410
Type of Mesh metric	Aspect Ratio
Min.	1.5196
Max.	70.605
Average	4.0336
Standard Deviation	1.0665

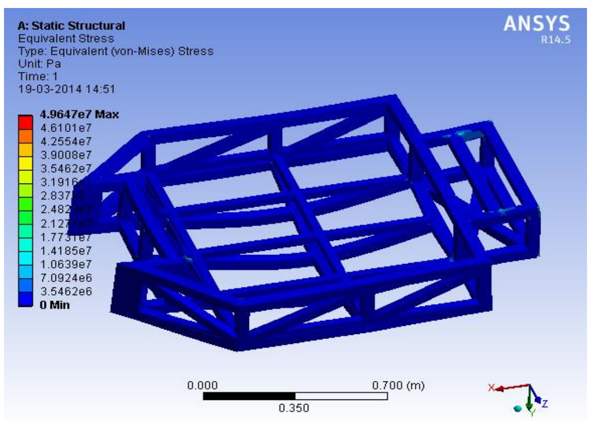

Figure 17. Equivalent Stress analysis of chassis

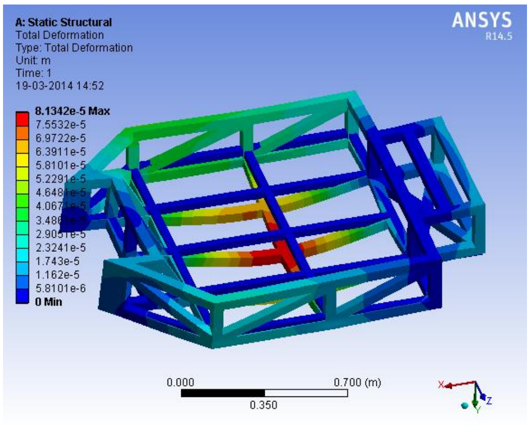

Figure 18. Total deformation of chassis

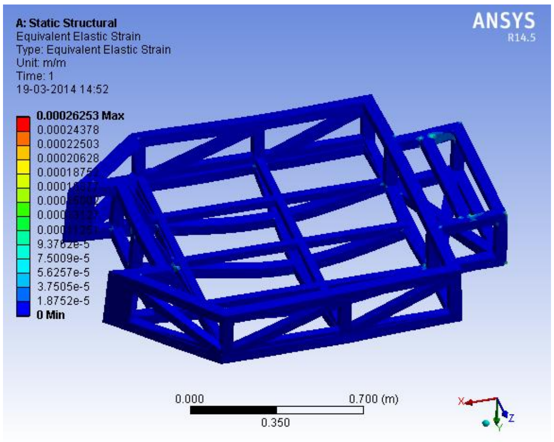

Figure 19. Equivalent strain induced on chassis

From the analysis the maximum deformation is found to be 8.13e-5 m, maximum equivalent strain is 0.00026 and maximum equivalent stress is 49 Mpa. Hence, the design is safe.

C. *Structural analysis of Wishbone*

The force exerted on the wishbone (A-arm) is on the location where shock absorber is attached to the arm. The analytical results are shown in figure 20 and figure 21.

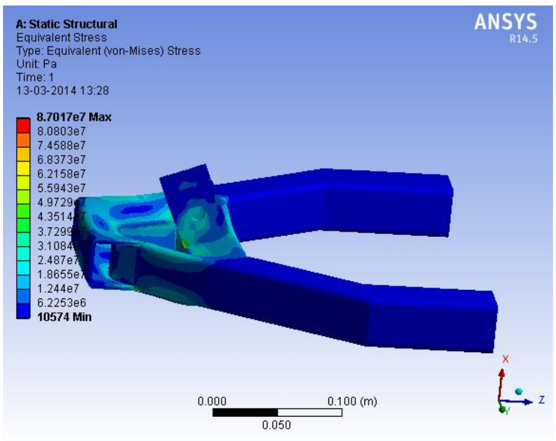

Figure 20. The Equivalent stress acting on the wishbone

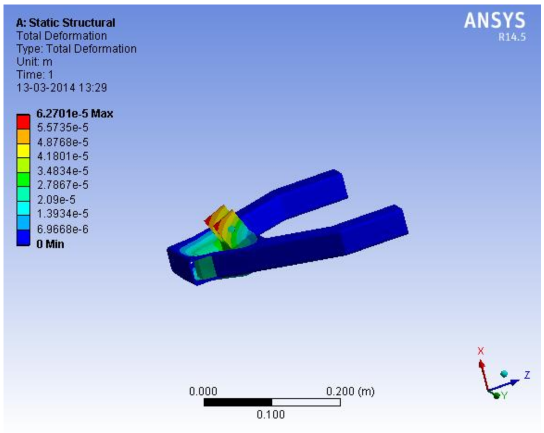

Figure 21. The deformation of the wishbone

From the analysis, it is found that Maximum deformation is 6.27e-5 m and Maximum equivalent stress is 87 Mpa. Hence the design is safe.

D. *Structural Analysis of Swing-arm*

The swing arm is placed on the single wheel side of the vehicle. The structural analysis is carried out when the force is applied by the shock absorber on the swing-arm and is shown in figure 22 and figure 23.

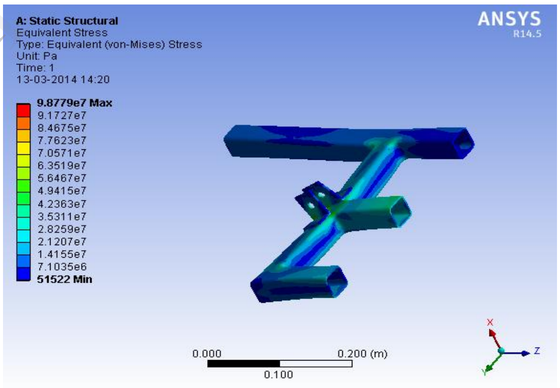

Figure 22. The Equivalent Stress acting on the Swing-arm

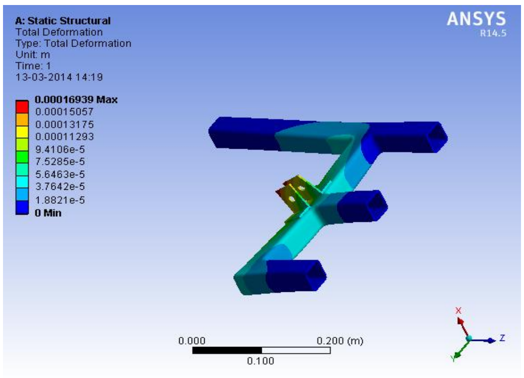

Figure 23. The deformation of Swing-arm

From the analysis it results that the maximum deformation is 0.00016 m, the maximum equivalent stress is 98.7 Mpa.

Therefore, from the above results, the design is considered to be safe.

E. Results of Analysis

Table 4. Analytical results

Name	Maximum equivalent Stress (Mpa)	Factor of Safety
Chassis	49.647	4.995
Wishbone	87.017	2.850
Swing-arm	98.779	2.510

The factor of safety of each component is shown in table 4. The assembled CAD model of entire vehicle is shown below in figure 24.

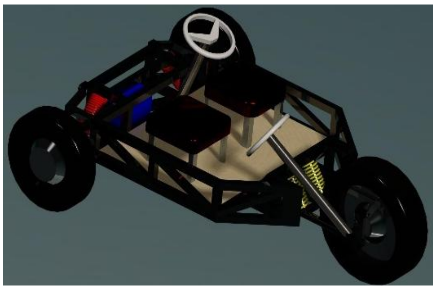

Figure 24. Assembled CAD model

V. CONCLUSION

In this paper, a suitable chassis is designed based on the accommodation of passenger, seat adjustments and suspension systems are designed based on the requirements. The turning radius of the all wheeled steering system is calculated and is found that the turning radius when steered on two wheel side is reduced by 83.9 cm and while steered on one wheel side, the turning radius is decreased by 26.83 cm. The Structural Analysis of Chassis, Wishbone and Swing arm shows that the maximum equivalent stress is less than the Yield Strength of the 1090 Mild Steel (low carbon steel) material which confirmed that the design is safe.

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